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Efficiency Improvement of dc/dc Boost Converter by Parallel Switches Connection

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Abstract

Efficiency improvement is the main concern for many researchers and manufacturers of the power electronic converters design. This paper presents a simple way to increase the efficiency of the dc/dc boost converter circuit by parallel switches connection inside the converter's circuit. These switches are the power diodes and Power transistors represented by IGBTs or MOSFET. A design of a suitable driver circuit is made which is fed by pulses that are generated by Arduino UNO microcontroller. This research circuit is tested through simulation in MATLAB Simulink, and experimentally. The better efficiency was in a parallel switching of each diode and IGBT transistor.

Keywords: dc/dc, Boost, Converter, Efficiency, Parallel Switch, IGBT driver

INTRODUCTION

The boost converter circuit is considered as a non-isolated dc/dc converter for stepping up the input voltage to a higher value. For many years, this converter is used widely in applications that require high dc voltage which is powered by low dc voltage. In power electronics, the term "switch" is referred to each device that is working in ON and OFF states. The diode is considered as a non-controlled switch whereas the IGBT or MOSFET transistors are considered as a controlled switch. For boost converter, these switches are managing the state of the converter for storing and releasing the energy for some period of time. The used switches are also contributing to the level of the efficiency of the converter. Sometimes, to increase the efficiency of the boost converter by using special switches as in the work that is presented by Jordi Everts et.al [1], where the used transistor is of enhancement mode AlGaN/GaN/AlGaN with high switching frequency up to 800 kHz. The measurements are taken at a 50% duty cycle. Another way to increase the efficiency of power electronic converter is by reduction of stray inductance inside the converter circuit as in [2] by a new switch module package instead of anti-parallel diode that is in parallel to the IGBT transistor. The converter efficiency is also improved by a passive snubber circuit connected to the IGBT switch of the boost converter [3]. The design is made by a soft switching. In [4], the efficiency of the boost converter can be improved by the proper inductor current selection. This paper presents a simple method of increasing the boost converter efficiency by a parallel connection of power electronic switches to the converter's circuit, with a design of a suitable driver circuit to firing the individual transistors that are connected in parallel. This paper contains an introduction about the ways to increase the boost converter efficiency, description of the boost converter operation with its mathematical models, the ways of connection of parallel IGBT switches and diodes, simulation and experimental results, and conclusions.

BOOST CONVERTER CIRCUIT

As shown in fig.1, the boost converter contains single of IGBT switch, diode, capacitor, and load. When the switch is ON, the inductor stores charge until the switch is OFF, then the stored charge is transitioned towards the load. The input voltage of the converter with the induced voltage of the inductor will make the output voltage higher than the input voltage. For lossless system, the voltage gain is calculated as in equation (1) [5]:

$$\frac{Vo}{Vi} = \frac{1}{1-D} \tag{1}$$

As there is a series resistance with the coil and capacitor of the converter, then by assuming that the resistance of the capacitors is neglected then the voltage gain will be as in equation (2) [6]:

$$\frac{Vo}{Vi} = \frac{1}{1-D}\left[\frac{(1-D)^2 R}{(1-D)^2 R + r_l}\right] \tag{2}$$

Where D represents the duty cycle, R is the load in Ohm, V_i and V_o are the output voltages respectively. Since it is difficult to know the value of the inductor series resistance r_l, then, by making a small test to the boost circuit practically and if the output voltage is measured while the input voltage and duty cycle is known then, the r_l value can be calculated as in equation (3):

$$r_l = \frac{R(1-D)\left[V_i - V_o(1-D)\right]}{V_o} \tag{3}$$

PARALLEL SWITCHES CONNECTION METHOD (DIODES AND IGBT)

As stated in [7-10], the connection of parallel IGBT switches have some merits and demerits. The merits are in low conduction and thermal losses. The demerits are in higher switching losses since many switches are gated at the same time.

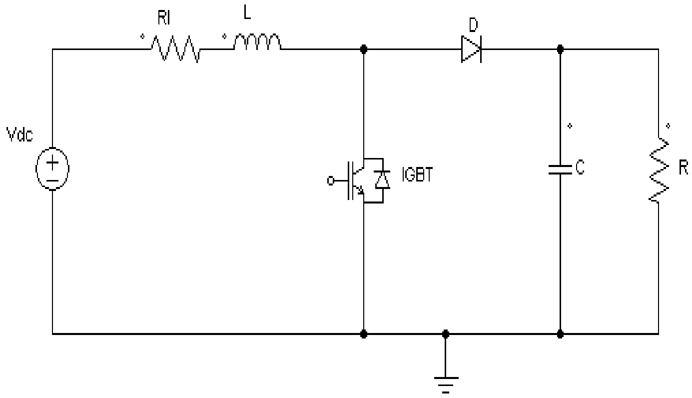

Figure 1: Boost converter circuit

By some optimization methods for the switches connections, better results can be achieved. Another issue can be gotten by using separate gate resistance or common gate resistance as in figure (2).

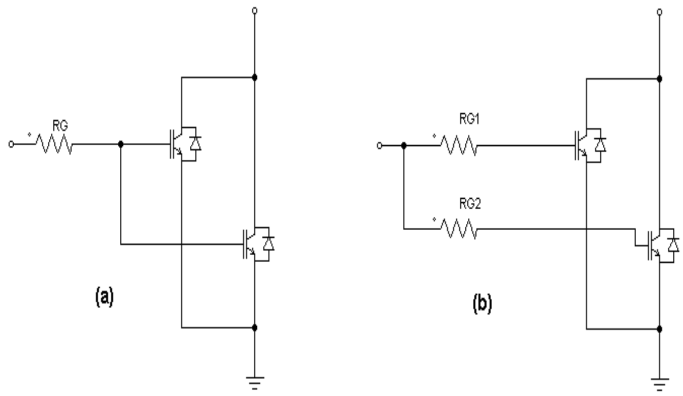

Figure 2: parallel IGBT connection, (a) common gate resistance (b) Individual gate resistance

In this research, the individual gate connection is better than common gate connection. Since it give a complete voltage pulse for each IGBT switch. Fig. (3), represents the driver circuits for each IGBT switch that are connected in parallel. Each IGBT should be identical completely to the other one. The parallel diode connection is good only if the number of diodes not more than three and both the diodes should be of the same type and capacity ratings.

SIMULATION RESULTS

The boost converter circuit is simulated at different conditions of parallel switches connection. In single switch connection and in parallel switches connection, the simulation results is same in all cases i.e. there is no impact of parallel switches connection in many simulation tools like Matlab Simulink, and Multisim. At different duty cycles, the boost converter is simulated by Matlab Simulink where, the input voltage is 24V, Inductor is 14mH, Capacitor is 20uF and the switching frequency is 25 kHz. The values of these parameters are calculated according to the related equations in [11]. The load is selected to be 100 Ohm. fig.(4) is a relation between the simulated boost converter efficiency with the duty cycle. The results show that, the efficiency is decreased when the duty cycle is increased since more current passes through the circuit.

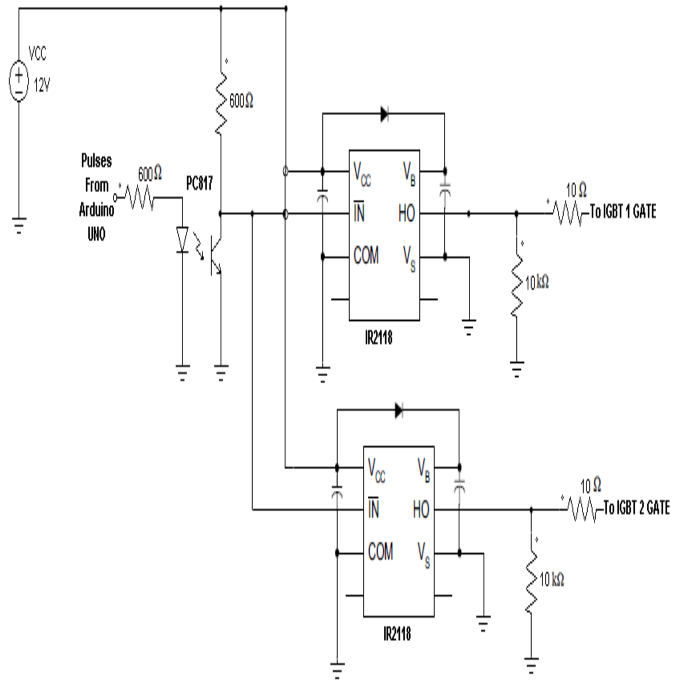

Figure 3: The proposed driver circuit for the individual gate resistance of parallel IGBTs

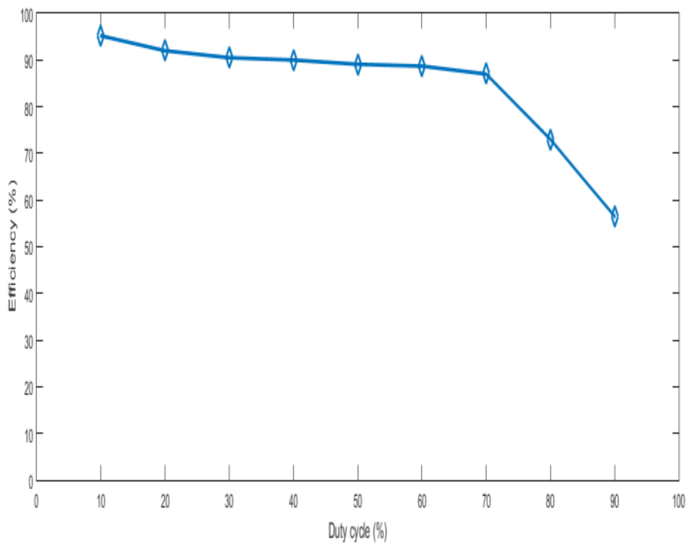

Figure 4: Relation between duty cycle with the Efficiency (by Matlab Simulink)

EXPERIMENTAL RESULTS

In the table (1), the boost converter component is used to implement the converter. The converter experimental test is shown in figure (5).

Table 1: Converter components used values.

Component	Value
L (Inductance)	14 mH, core (ETD 49/25/16-3C90)
IGBT (all)	SGH80N60UFD
Diodes (all)	RHRG70120
C (Capacitor)	20 µF
Input voltage	24 (dc Voltage)
Switching frequency	25 kHz

Figure 5: The experimental test

The pulses to the IGBT switches are generated by using Arduino UNO microcontroller via a driver circuit. The pulses frequency is 25 kHz. The driver circuit is exactly as shown in figure (3) to make individual pulses to the IGBT switches that are connected in parallel and also making the pulses to be fast enough with small rise and fall times. The Pulses from the Arduino UNO are isolated by an opto-coupler PC817.Two driver ICs of IR2118 are used to get the individual pulses to the IGBTs. The driver ICs takes the signal from the opto-coupler to make the signals have a fast rise and fall times. By using Hantek 6022BE PC oscilloscope, the voltage at each of IGBT collector and the output voltage are measured as shown in figures (6 and 7) respectively.

Figure (8), is zoomed figure to represents the relation between the duty cycle and converter's efficiency at range of duty cycles from (10-70) %. This range of duty cycle is selected because below or higher than it, the converter performance and efficiency is reduced. If only two diodes are connected in parallel in the converter circuit, the efficiency results are better than the single diode and IGBT switches connection. If only two IGBTs are connected in parallel in the converter, the efficiency is more improved. In this paper, the condition of

Figure 6: IGBT collector voltage (Volt)

Figure 7: Output voltage of the boost converter (Volt)

highest efficiency is reached when; two IGBTs and diodes are connected in parallel in the boost converter circuit at the same time.

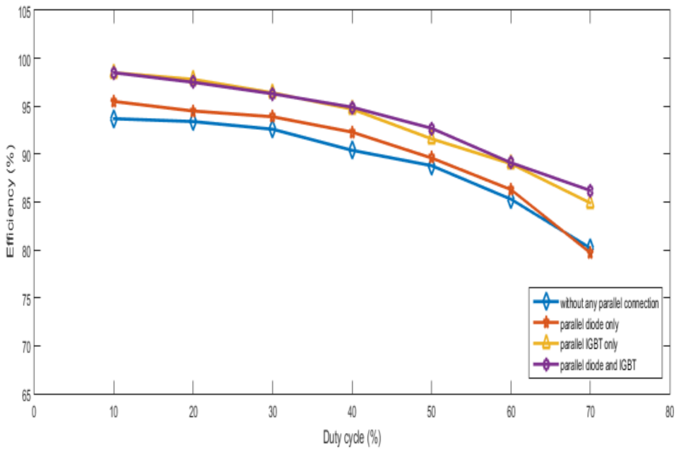

Figure 8: Practical results at different cases of switches connection

Imroving the effeciency of boost converter means also increasing its output voltage. Another comparism can be made with the output voltage of loss-less system as in equation (1) , the voltage at the simulation results, and experimentally at parallel switches conncection of both IGBT and diode where, the parallel switches connection gives better results than the simulation results and nearer to the results of loss-less system as shown in figure (10). This means that the parallel switches connection of boost converter conributes in decreasing the swihches ON resistance and improving the converters effeciency.

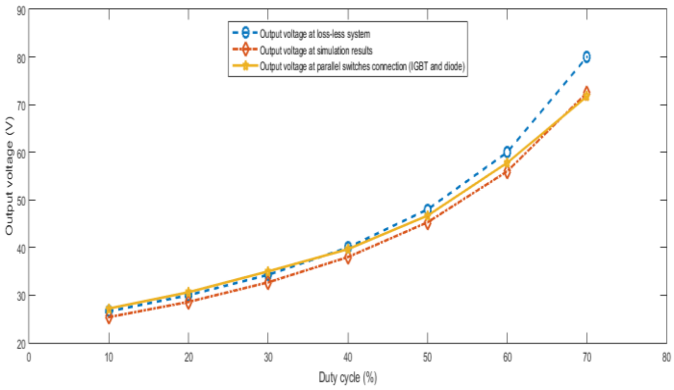

Figure 9: Comparism of Output voltage of boost converter at (Loss-less system, in Simulation, and Experimentally)

CONCLUSION

In this paper, the parallel connection of diodes and IGBT switches in the boost converter circuit is good way to increase the efficiency of this converter. Also, it makes the switches of the converter share the same thermal and conduction losses and thus, it can increase the output power of the converter. The individual IGBT gate resistances that are fired by a proper driver circuit are better in efficiency than the common gate resistance connection.

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